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Star clusterings in the Carina complex: *UBVRI* photometry of NGC 3324 and Loden 165 ⋆

G. Carraro[1,2], F. Patat[2], and H. Baumgardt[3]

[1] Dipartimento di Astronomia, Universitá di Padova, vicolo dell'Osservatorio 5, I-35122, Padova, Italy
[2] European Southern Observatory, Karl-Schwartzschild-Str 2, D-85748 Garching b. München, Germany
[3] Department of Mathematics and Statistics, University of Edimburgh, Edinburgh EH9 3JZ, UK
e-mail: carraro@pd.astro.it,fpapat@eso.org,holger@maths.ed.ac.uk

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Abstract. We report on $UBVRI$ photometry of two $5' \times 5'$ fields in the region of the young open cluster NGC 3324. One of our fields covers the core region, while the other is closer to the tidal radius of the cluster. Our study provides the first CCD photometry of NGC 3324. We find that the cluster is very young and probably contains several pre Main Sequence (MS) stars. 25 members are identified on the basis of their position in the $(U-B)$ vs $(B-V)$ diagram. We investigate the relation of the red super-giant HD 92207 with NGC 3324, suggesting that it probably does not belong to the cluster.
Our second field is close to Loden 165, a possible cluster of stars that has never been studied so far. We show that this object is a probable open cluster, much older than NGC 3324 and much closer to the Sun.

Key words: Photometry : optical–Open clusters and associations : NGC 3324 : individual -Open clusters and associations : Loden 165 : individual.

1. Introduction

Aiming at collecting a homogeneous and complete sample of all the star clusters in the Carina complex (Janes et al 1988), we have carried out a program dedicated at obtaining high quality multicolor CCD photometry of all the star clusterings known or presumed to lie close to η Carinae.
We already reported on Bochum 9, 10 and 11 in Patat & Carraro (2001). In this work we concentrate on the results we have obtained for NGC 3324 and Loden 165, while the remaining clusters (see Feinstein 1995 for a review on the subject) will be discussed in Romaniello et al (2001).

Send offprint requests to: G. Carraro (carraro@pd.astro.it)
⋆ Based on observations taken at ESO La Silla.

NGC 3324 is particularly interesting because it is believed to be extremely young and to have a significant pre-MS population. Moreover the membership of the red supergiant star HD 92207 (HIP 52004) to NGC 3324 is still uncertain. Although the projected distance of HD 92207 from the cluster center seems much larger than the cluster radius, there are reasons to believe that this star is a member of NGC 3324, although we are far from having a firm answer to this problem (Baumgardt et al. 2000).
As for Loden 165 (C1035-584 according to IAU), no data are available in the literaure to our knowledge. Therefore it is not clear whether it is a star cluster or not, and whether it is related or not to the Carina complex.
The layout of the paper is as follows: Section 2 presents the data acquisition and reduction. In Section 3 we discuss the open cluster NGC 3324 and the relation of HD 92007 to it. Section 4 is dedicated to Loden 165, a triplet of stars that Lodèn (1973) suggested to be the signature of a possible star cluster, demanding further investigation.
Our conclusions are summarized in Section 5.

Table 1. Basic parameters of the observed objects. Coordinates are for J2000.0 equinox. For Loden 165, the star HD 303088 is used as center of the system.

Name	α	δ	l	b
	$hh:mm:ss$	$^o:':''$	^{o}	^{o}
NGC 3324	10:37:18.8	-58:37:36.2	286.22	-0.18
Loden 165	10:35:55.8	-58:44:02.7	286.12	-0.36

2. Observations and Data Reduction

Observations were conducted at La Silla on April 13-16, 1996, using the imaging Camera (equipped with a TK coated 512 × 512 pixels CCD #33) mounted at the Cassegrain focus of the 0.92m ESO–Dutch telescope. All

nights, with the only exception of the first half of April 14, were photometric with a seeing ranging from 1″ to 2″. The scale on the chip is 0″.44 and the array covers about 3′.3 × 3′.3 on the sky. Due to the projected diameter of the objects and the relatively small field of view, it was necessary to observe four fields for the same object. Additional details on the observations are given in Table 2, while the covered fields are shown in Fig. 1.

Table 2. Journal of observations of NGC 3324 (April 16, 1996) and Loden 165 (April 15, 1996).

	NGC 3324			Loden 165		
Field	Filter	Exp. Time (sec)	Seeing (″)	Filter	Exp. Time (sec)	seeing (″)
#1	U	10	1.2	I	20	1.8
	B	3	1.1	I	120	1.8
	B	120	1.1	R	5	1.8
	V	3	1.1	R	60	1.8
	V	60	1.1	V	10	1.8
	R	3	1.1	V	120	1.8
	R	60	1.1	B	15	1.8
	I	3	1.1	B	300	1.8
	I	120	1.1	U	600	1.9
#2	I	3	1.1	U	600	2.0
	I	120	1.1	B	15	1.8
	R	3	1.1	B	300	1.8
	R	30	1.1	V	10	1.7
	V	3	1.1	V	120	1.7
	V	60	1.1	R	5	1.5
	B	3	1.1	R	60	1.6
	B	120	1.1	I	20	1.6
	U	10	1.1	I	120	1.7
#3	U	10	1.2	I	20	1.5
	B	3	1.2	I	120	1.5
	B	120	1.2	R	5	1.5
	V	3	1.2	R	60	1.6
	V	30	1.2	V	10	1.8
	R	3	1.3	V	120	2.0
	R	30	1.3	B	15	1.8
	I	3	1.3	B	300	2.3
	I	120	1.3	U	600	1.9
#4	I	3	1.5	U	600	1.9
	I	120	1.4	B	15	1.6
	R	3	1.5	B	300	1.6
	R	30	1.4	V	10	1.7
	V	30	1.4	V	120	1.7
	V	60	1.3	R	5	1.7
	B	3	1.4	R	60	1.7
	B	120	1.4	I	20	1.7
	U	10	1.5	I	120	1.5

To allow for a proper photometric calibration and to asses the night quality, the standard fields RU149, PG1323, PG1657, SA 109 and SA 110 (Landolt 1992) were monitored each night. Finally, a series of flat–field frames on the twilight sky were taken. The scientific exposures have been flat–field and bias corrected by means of standard routines within *IRAF*. Further reductions were performed using the DAOPHOT package (Stetson 1991) under the *IRAF* environment.

The instrumental magnitudes have been transformed into standard Bessel UBVRI magnitudes using fitting coefficients derived from observations of the standard field stars from Landolt (1992), after including exposure time normalization and airmass correction. Aperture corrections have also been applied. Typical RMS errors in the zero points amount at 0.02 mag. More details on the data reduction have been presented in Patat & Carraro (2001).

3. The open cluster NGC 3324

NGC 3324 (OCL-819) is a compact star clusters embedded in a filamentary elliptically shaped nebulosity which forms a bridge connecting the cluster core with HD 92207 (see Fig. 1). The complex is believed to be located inside the Carina spiral arm.

3.1. Previous results

NGC 3324 was firstly studied by Moffat & Vogt (1975), who provided photoelectric photometry for 12 stars within 1′ of the cluster core. The authors note that the cluster is surrounded by a large nebulosity (the HII region G 31). The strong HII emission supports the idea that the cluster is rather young, together with the possible presence of contracting pre MS stars. According to Moffat & Vogt (1975) the cluster is located 3.28 kpc from the Sun, and suffers from a mean reddening E$(B-V) = 0.45\pm0.05$.
Later this cluster was investigated in detail by Clariá (1977), who obtained UBV photo-electric photometry for 45 stars in a region of about $6' \times 6'$, extending the photometry down to V=14. From this study, Clariá concluded that NGC 3324 is very young (2.2×10^6 yrs), has a mean color excess of E$(B-V) = 0.47\pm0.08$, and is 3.1 kpc away from the Sun, basically confirming Moffat & Vogt (1975) results.
Moreover Clariá discusses the membership of HD 92207 to NGC 3342. He suggests that the star is a foreground red supergiant ($V = 5.46$, $(B-V) = 0.50$, $(U-B) = -0.24$) , since it is far away from the cluster and appears to have a somewhat lower distance modulus. On the other hand Forte (1976) comes to a different conclusion, emphasizing the possible membership since the star seems to be part of the same complex of NGC 3324, at least looking at the strong gaseous structure surrounding both the cluster and the star. The same conclusion is drawn by Baumgardt et al. (2000). In fact the cluster has an angular diameter of 5′ (Lynga 1987), which means a core radius of about 3′ and a tidal radius of about 12′. Since HD 92207 (HIP 52004) lies about 7′ southwards of NGC 3324, it stays inside the cluster tidal radius. This might lead to the suggestion that

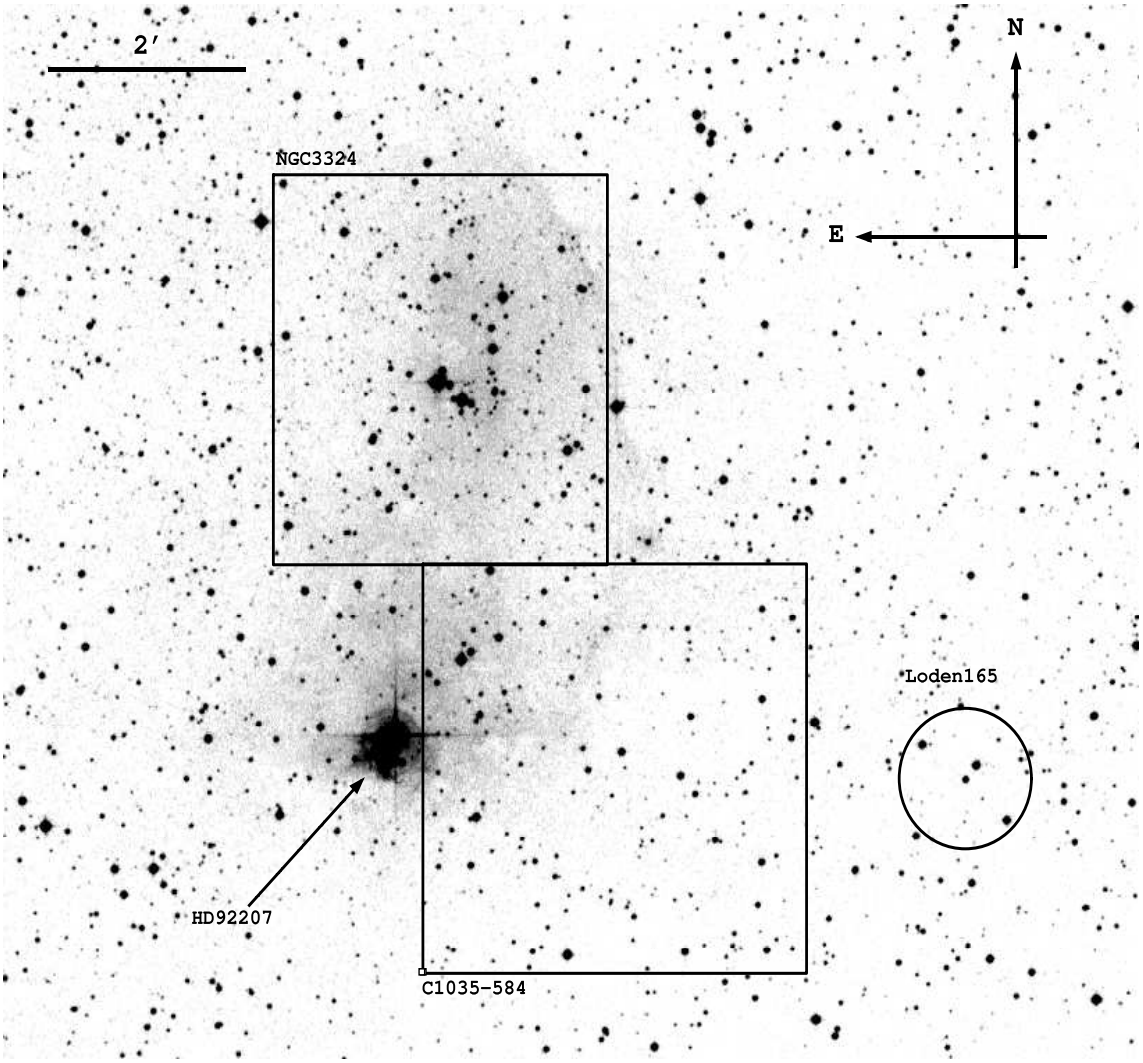

Fig. 1. DSS map of the region around NGC 3324. The region of the center is covered by by the upper left square, which is a mosaic of the observed fields, whereas the lower right square defines the mosaic of the fields covered by our photometry for the outer cluster parts. The circle confines the three stars observed by Lodén (1975). The bright star on the left of our second field is HD 92207, which is presumed to be part of NGC 3324. Note the strong nebulosity which encloses the cluster and HD 92207.

HIP 52004 is a probable member of NGC 3324. This cluster has in fact a very concentrated core, and the crossing time in the center should be very short. From time to time some stars might probably be kicked out of the cluster, and this can even happen to the most massive star.

3.2. The present study

We provide $UBVRI$ photometry for 1002 stars in the region of NGC 3324, up to about V = 20. Our photometry is basically consistent with previous ones for the stars in common (12 in total). In detail we find:

$V_{CPB} - V_{MV} = 0.028 \pm 0.095$

$(B-V)_{CPB} - (B-V)_{MV} = 0.056 \pm 0.078$

$(U-B)_{CPB} - (U-B)_{MV} = 0.080 \pm 0.107$

We emphasize that we did not consider Moffat & Vogt (1975) stars #6 and #9, since they are blended. As for Clariá (1977), the comparison of the common stars (see Table 3) provides:

$V_{CPB} - V_C = 0.003 \pm 0.045$

$(B-V)_{CPB} - (B-V)_C = 0.021 \pm 0.047$

$(U-B)_{CPB} - (U-B)_C = 0.082 \pm 0.095$

From this comparison we exclude stars # 41, 44 and 45, which deviate more significantly (see Table 3), probably because they are either at the limit of the Clariá (1977) photometry or blended (see Fig. 2). In all the above equations CPB stands for the present study, MV for Moffat

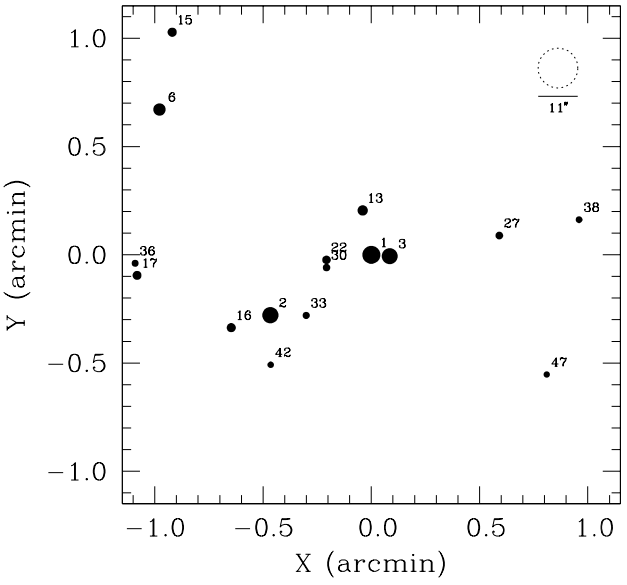

Fig. 2. Map of all stars brighter than V = 14.5 in NGC 3324. Note that all the star groups usually blended in previous photo-electric photometries, are now resolved. The size of the circles is proportional to the magnitude of the stars. The upper right dashed circle is the size of the diaphragm (11″) in the photo-electric photometry of Moffat & Vogt (1975).

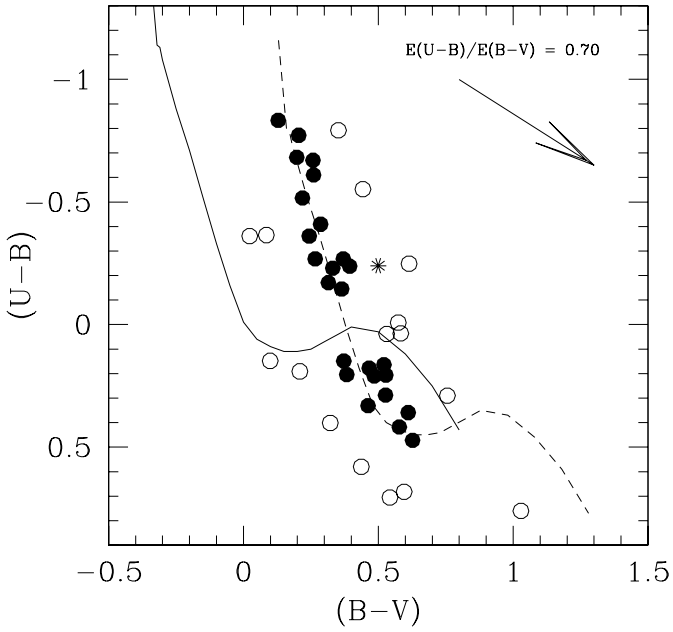

Fig. 3. Two colors diagram of NGC 3324. The arrow indicates the reddening vector, while the continuous and dashed lines are the empirical ZAMS from Schmidt-Kaler (1982). Cluster probable members are indicated with filled symbols, while non members with open symbols. The position of HD 92207 is indicated with a starred symbol. See the text for details

& Vogt (1975) and C for Clariá (1977).

In both cases the differences are not negligible. In fact Moffat & Vogt (1975) adopted a 11″ diaphragm (Moffat, private communication), while Clariá (1977) a 14″ diaphragm (Clariá, private communication). Since the cluster is rather compact, and several stars have mean separation less than 5″, we expect that stars blending is effective and is probably the cause of the reported differences. We cannot however exclude possible deviations due to differences in the adopted photometric systems.

CCD photometry allowed us to resolve blended stars and to obtain fairly precise measurements. In fact we find that the photometric errors amount at 0.03, 0.04, 0.04, 0.0.4 and 0.05, at V = 12, 14, 16, 18 and 20, respectively.

3.3. Reddening

The position of the studied stars in the two color diagram is shown in Fig. 3. In the same plot we show an unreddened sequence (solid line) from Schmidt-Kaler (1982), and the same sequence shifted by E$(B-V) = 0.48$ and E$(U-B) = 0.34$ (dashed line). Most of the stars actually lie along this second ZAMS, sharing the same reddening of E$(B-V) = 0.48\pm0.03$. All these stars are considered probable members. They amount at 25 stars (filled circles) up to $V = 15$, and have been collected in Table 3. The remaining stars are probably non-members.
Our estimate for the reddening is consistent with that obtained by Clariá (1977). HD 92207 (starred symbol) lies somewhat outside the cluster mean line, and this raises some doubts on its membership to NGC 3324.

3.4. Age and distance

The Color Magnitude Diagrams (CMDs) of NGC 3324 in different colors are shown in Figs. 4 and 5. Fig. 4 shows the reddening corrected CMD in the planes $V_o-(B-V)_o$ (left panel) and $V_o-(U-B)_o$ (right panel), where only the probable cluster members have been plotted. super-imposed is the empirical ZAMS from Schmidt-Kaler (1982) shifted by E$(B-V) = 0.48$ and E$(U-B) = 0.34$, respectively. The vertical shift provides an estimate of the apparent distance modulus $(m-M) = 13.9\pm0.03$, where the uncertainty has been computed allowing the reddening to lie in the range derived in the previous section. Therefore the corrected distance modulus $(m-M)_o$ turns out to be 12.41 ± 0.03, in agreement with Clariá's (1977) estimate. Accordingly, the distance of NGC 3324 to the Sun is 3.0 ± 0.1 kpc.
On the other hand, Fig. 5 shows the CMD in the planes $V-(V-I)$ and $V-(V-R)$. Note the extension of the MS

Table 3. Photometry of the stars identified as probable members in the field of NGC 3324. C indicates Clariá (1977) numbering.

ID	*C*	$X(pixel)$	$Y(pixel)$	V	$(B-V)$	$(U-B)$	$(V-R)$	$(V-I)$
1	2	462.14	37.15	8.236	0.129	-0.833	0.128	0.380
2	4	398.57	-0.87	9.018	0.205	-0.772	0.160	0.319
6	9	328.74	128.70	10.838	0.258	-0.670	0.223	0.425
7	11	494.64	283.34	11.006	0.198	-0.682	0.203	0.377
13	19	456.71	65.10	11.789	0.260	-0.610	0.216	0.442
15	31	336.71	177.33	12.371	0.286	-0.409	0.197	0.410
16	33	373.93	-8.73	12.461	0.219	-0.516	0.189	0.365
17	35	314.59	24.20	12.587	0.394	-0.238	0.325	0.642
20	36	110.61	291.96	12.773	0.244	-0.361	0.168	0.350
22		433.90	33.98	12.838	0.315	-0.171	0.233	0.472
26		179.05	-235.51	13.264	0.331	-0.230	0.249	0.534
29		100.02	289.55	13.530	0.372	0.149	0.425	0.760
30		433.95	29.10	13.459	0.266	-0.268	0.070	0.456
31	41	406.10	344.81	13.547	0.370	-0.268	0.268	0.531
32		766.83	461.47	13.493	0.466	0.178	0.302	0.528
33	44	421.13	-1.04	13.696	0.364	-0.145	0.274	0.556
37		460.13	294.91	13.974	0.578	0.418	0.396	0.761
38		593.03	59.27	13.955	0.521	0.164	0.315	0.597
39		645.97	327.91	14.005	0.527	0.288	0.315	0.571
40		571.66	234.97	14.117	0.611	0.359	0.473	0.880
41		531.51	210.38	14.134	0.528	0.206	0.392	0.753
42	45	398.77	-32.10	14.148	0.383	0.204	0.268	0.526
43		16.40	-162.82	14.172	0.485	0.210	0.295	0.575
51		460.15	402.78	14.518	0.627	0.472	0.370	0.639
61		300.85	208.82	14.891	0.462	0.331	0.315	0.634

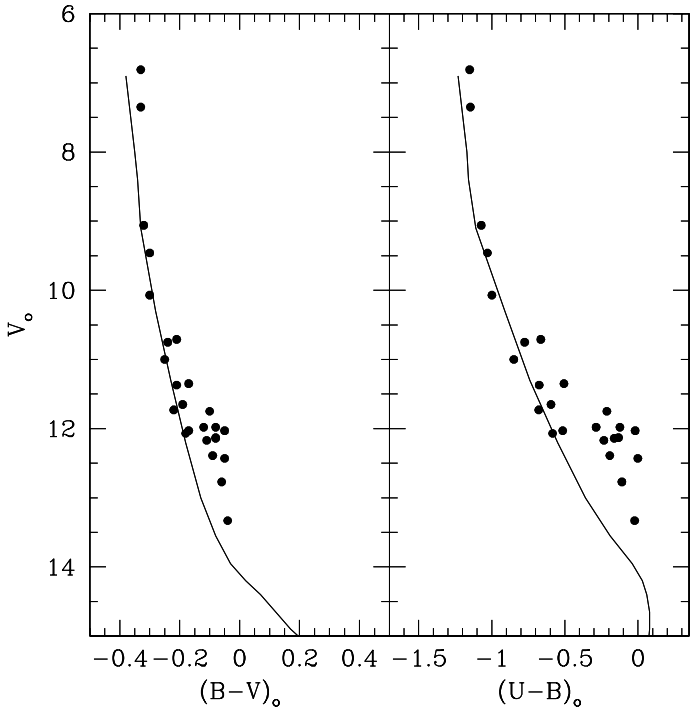

Fig. 4. The reddening corrected CMDs of NGC 3324. Only probable members are plotted, together with the Schmidt-Kaler sequence. See text for details.

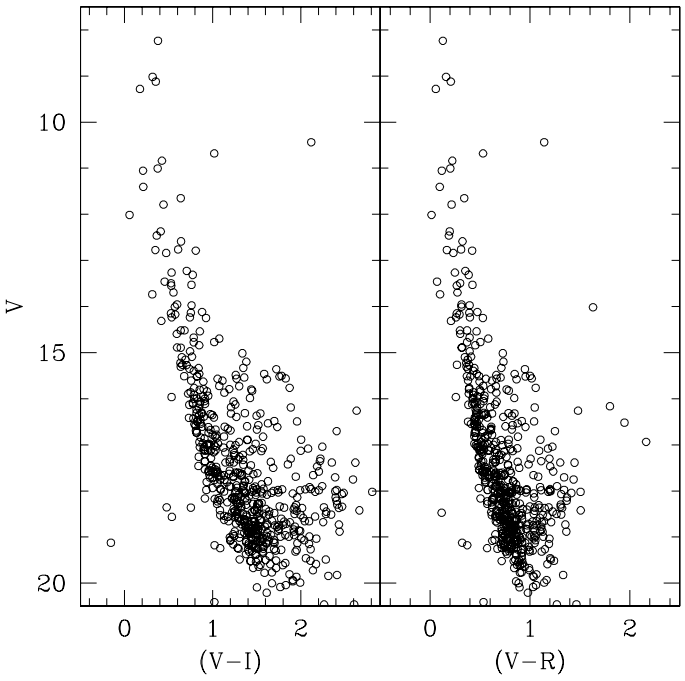

Fig. 5. The CMDs of NGC 3324 for all the detected stars.

down to V = 20, and the widening of the MS at increasing magnitudes. Since the width of the MS below $V = 14$ is much larger than the mean photometric errors, it is quite probable that many pre-MS stars are actually present in this cluster (see below).

Estimating the precise age of this cluster is a challenging task. Looking again at the CMDs, apparently there are no bright stars which are significantly redder than the MS. This means that all the stars we see are still in the H-burning phase. The exact age of the cluster strongly depends on the membership of HD 92207. If this star belongs to the cluster, it must be an evolved star due to its red color. In this case the cluster would be as old as 2-3 Myr, as Clariá (1977) pointed out. On the other hand, if HD 92207 does not belong to the cluster, the 2-3 Myr estimate has to be considered only as an upper limit for the age of NGC 3324.

3.5. Looking for pre-MS candidates

Looking carefully at Fig. 4, it seems that the clump of stars with $V \leq 14.0$ lies away from the ZAMS towards the red. This may be an indication that these stars are still in the pre MS phase ad are still approaching the ZAMS. In addition the appearance of the CMDs in Fig 5 points towards the same direction. The MS gets wider at increasing magnitude, and its width is significantly larger than expected from the photometric errors. Moreover since we are covering a rather small region of the cluster, the contamination of field stars should not be very significant.
Much firmer conclusions can be obtained by measuring the H_α emission from these candidates or by obtaining infrared photometry (Hillebrandt et al 1998).

3.6. Absolute proper motion and the membership of HD 92207

The Hipparcos Catalogue (ESA 1997) provides absolute proper motions for 120.000 stars, covering the whole sky. It is supplemented to fainter magnitudes by the Tycho 2 Catalogue (Høg et al. 2000). The proper motion of HD 92207 was measured by Hipparcos and we could identify 4 other potential members of NGC 3324 in Tycho 2. All stars are listed in Table 3, and are considered probable members on the basis of the position in the CMD - they lie along the MS- and because they have the same reddening. From the Tycho 2 members, the mean cluster motion turns out to be $\mu_{\alpha*} = -10.50 \pm 1.19$ and $\mu_\delta = 3.79 + -1.16$ mas/yr. There is an agreement with the proper motion of HD 92207 in μ_δ, but a significant discrepancy in μ_α. Comparing the proper motions, we derive a membership probability of 5.5% for HD 92207 (see Baumgardt et al 2000 for the method to assign probability) , which argues against the membership of this star in the cluster. However, the mean cluster motion is not very well defined, since it is derived from four stars only. The proper motion alone does therefore not rule out the membership of HD 92207.

Table 4. Proper motions (in mas/yr) of possible members of NGC 3324. Data is taken from Tycho 2, except for HD 92207, which has been taken from Hipparcos.

ID	Star		$\mu_{\alpha*}$	μ_δ
1	GSC 8613	1825	-10.4 ± 4.2	6.8± 4.0
2	GSC 8613	780	-8.0 ± 1.5	5.4± 1.5
6	GSC 8613	121	-16.5 ± 3.6	1.7± 3.4
7	GSC 8613	947	-15.6 ± 2.8	-1.1 ± 1.6
	HD 92207		-7.46 ± 0.53	3.22 ± 0.44

HD 92207 seems also to have a higher reddening ($E(B-V) = 0.52$) than the mean NGC 3324 value (0.48) , and according to Clariá (1977) a lower distance (1.9 kpc).

Summarizing, we conclude that HD 92207 is unlikely to be a genuine member of NGC 3324. It might however be spatially close to this cluster, since the HII gas in this area surrounds the star and seems to connect it with the cluster center. But this may just be a projection effect.

4. The star cluster Loden 165

Nothing exists in the literature about this cluster, designed as C1035-584 by the IAU. It was suggested to be a possible physical group by Lodén(1973) who measured three stars (HDE 303088, HDE 303089 and HDE 303090), and found that they are of A0-A2 spectral type. Lodén suggests that this triplet is 1 kpc distant from the Sun and suffers from a low extinction, which he found to be $E(B-V) = 0.11$.

Table 5. Basic parameters of Loden 165 stars.

Name	V	$(B-V)$	$(U-B)$	*Sp.Type*
HD 303088	11.20	0.13	0.15	A2
HD 303089	11.39	0.13	0.11	A0
HD 303090	11.35	0.18	0.18	A2

Since this triplet appears rather compact, the stars might in principle constitute a poor open cluster or an association. The coordinates of the triplet are given in Table 1, from which it can be seen that Loden 165 lies about $4'$ west of our second field. This can also be seen in Fig. 1, where Lodén's stars are enclosed in a small circle, whereas the field covered by us is identified by the lower right square.

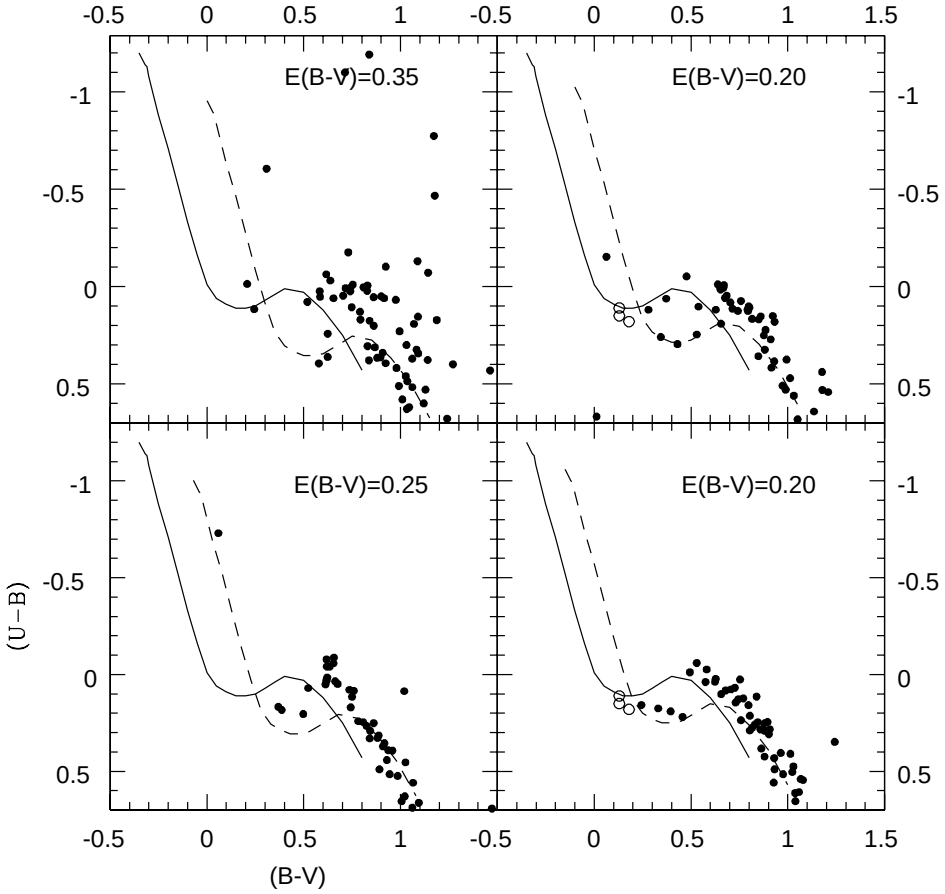

Fig. 6. Two colors diagrams for all the stars in the region of Loden 165, grouped according to the targeted fields (see Table 1). In the upper panels two different sequences are clearly visible. Open symbols indicate the stars studied by Lodén (1973).

The area covered by our observations does not include Loden 165 stars. However this field is very interesting due to its vicinity to NGC 3324. According to the estimate of its tidal radius (12′), the field covered by us could simply be a portion of the halo of NGC 3324.
Alternatively, we could be simply looking at a region of Loden 165, whose nature of cluster has never been clarified.

4.1. The two colors diagram

The two color diagram for the stars in the field of Loden is shown in Fig. 6, where we have divided the regions according to the observed fields which, combined together, cover the region shown in Fig. 1. It is clear that the region is dominated by differential reddening. In particular in the upper frames the stars are rather dispersed, and seem to show several parallel sequences, characterized by a different mean reddening. The larger value of the reddening in this region with respect to the other fields, is marginally compatible with the reddening of HD 92207 and NGC 3324, which lie very close.
On the opposite side the reddening is lower and close to the one reported by Lodén for his triplet. However, on the average, the mean reddening of this region is much lower than in the case of NGC 3324 (cfr. Section 3.3), being between $0.20 - 0.35$. The mean reddening in this region, averaging over all four fields, turns out to be $E(B-V) = 0.25 \pm 0.08$.
The three stars of Loden 165 are shown in the right panels of Fig. 6 with open symbols. They seem to lie somewhat apart from the ZAMS in both panels, supporting the conclusion that they are a triplet of stars lying closer to the Sun and suffering from a smaller reddening.

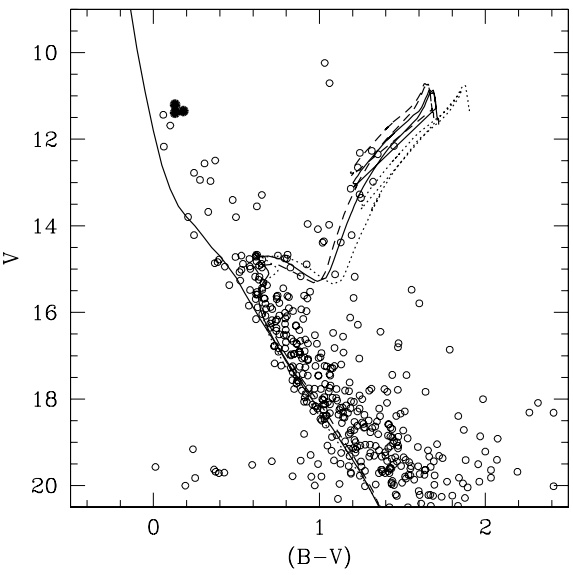

Fig. 7. CMD in the region of Loden 165. Superimposed are three solar metallicity isochrones for the ages of 2 (dotted line), 3 (solid line) and 4 (dashed line) Gyrs (Girardi et al 2000). The three filled circles indicate Lodén's triplet.

4.2. The CMDs

The global CMD of Loden 165 is shown in Fig. 7. The general appearance is very different from the CMD of NGC 3324 (cfr. Figs. 4 and 5). There is a clear MS extending for about 5 magnitudes from $V = 20$ to $V = 15$. At brighter magnitudes it sharply drops, showing a clear Turn Off at $V = 14.5$, $(B - V) = 0.25$. The population of bright MS stars is very poor, while there is clear evidence of a sub-giant and red giant branch population. This leads to the suggestion that the cluster is rather old, at least much older than NGC 3324.

To have an idea of the cluster age and distance we superimposed three solar metallicity isochrones for the ages of 2 (dotted line), 3 (solid line) and 4 (dashed line) Gyrs from the Padova models (Girardi et al. 2000). It turns out that the best match is obtained with the 3 Gyrs isochrone by assuming the mean reddening derived above. As a consequence, the apparent distance modulus turns out to be (m-M) = 12.1. The corrected distance modulus turns out to be $(m - M)_o = 11.42$, which puts this object 1.9 kpc from the Sun. In the same plot we have included also the Lodén triplet using filled circles. The most plausible conclusion is that they seem to be simply field stars.

5. Conclusions

We reported on $UBVRI$ photometry of two stellar fields in the open cluster NGC 3324. Our results basically confirm previous photo-electric investigations. We find 25 probable members and suggest that the cluster is younger than 3 *Myr*, suffers from a mean extinction of $E(B - V) = 0.48 \pm 0.03$, and lies 3.0 ± 0.1 kpc from the Sun. By extending the member list up to $V = 14.5$, we suggest the possibility that some stars are actually pre-MS candidates, an hypothesis which deserves further investigation to be confirmed. Pre-MS objects in fact would provide an additional constraint on the cluster age. The A super-giant HD 92207 is probably not a member of NGC 3324, but might be spatially close to the cluster.

Loden 165, an object never studied so far, is an old star cluster with an age of approximately 3 Gyrs. The estimates of the age, reddening and distance are very different from those of NGC 3324, suggesting that Loden 165 has presumably nothing to do with the Carina open cluster system.

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